*Channelization and Spoiling in Gulf Coast & South Atlantic Estuaries** †

ABSTRACT

Channels and spoil banks are now a part of the estuarine environment. Several methods of construction are used that permit varying degrees of control over resulting spoil. Mechanical excavation with bucket dredges or draglines provides good spoil control on a small area. Hydraulic excavation, however, requires large spoil areas and affords poor control unless the spoil is removed from the construction site (hopper dredge) or retained within ring levees.

More than 200,000 acres of shallow coastal bays (not including marshes) in the Gulf and South Atlantic areas have been lost by dredging and filling over the past 20 years. In Texas alone, about 700 miles of Federal navigation channels have altered 13,000 acres of shallow bay bottoms and destroyed 7,000 acres of brackish marsh by deepening. Spoil from these channels has filled 55,000 acres of shallow bays and covered 23,000 acres of brackish marsh. It is not known how much estuarine habitat has been obliterated by private channels.

Other disadvantages of channelization and spoil dumping include segmentation of bays which promotes shoaling; increased saltwater intrusion; increased flushing time; altered tidal exchange, mixing, and circulation; increased turbidity; and loss of submerged aquatic vegetation. None of these changes, however, are as significant as the direct physical loss of habitat.

Advantages of channels and spoil deposition include connection of isolated waters and marshes to make them available as fish nursery areas, provision of routes of escape or refuge for fish during cold periods, improvement of water exchange and circulation, and release of nutrients trapped in bottom sediments.

Suggestions are given for planning channels and depositing spoil to reduce the loss of vital bay and marsh habitat. Research is needed so we can learn how to rehabilitate thousands of acres of barren spoil areas in our estuaries.

INTRODUCTION

Navigation channels are now part of the estuarine environment. Some estuaries have deep, wide channels capable of accommodating

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large ocean-going vessels; many have channels large enough to accommodate barge traffic; and others have only small channels for shallow-draft boats. Many estuaries have both large and small channels. Usually, the greater the population of people in the vicinity of an estuary the more numerous and larger the channels. I do not know of an estuarine system along the south Atlantic or northern Gulf of Mexico coast that does not have a channel of some kind.

Generally, the larger channels are perpendicular to the coastline and traverse an estuary from its connection with the sea to its headwaters. Barge channels usually parallel the coastline, pass laterally through an estuary and continue across marshes and uplands to connect with another estuary. The smaller channels usually afford transport from the shallow shoreline zone or small tributary to deeper waters of an open bay or to a larger channel. Thus, as estuary frequently is criss-crossed by many channels of different dimensions. The present trend is to enlarge existing channels and to construct more new large channels to accommodate the bigger vessels and barges that are being put into service.

As the channels in an estuary develop, they eventually occupy every conceivable type of habitat or zone—the tidal connection with the sea, open bays, oyster reefs, shallow shoreline zones, beaches, tidal flats, beds of submerged aquatic vegetation, adjacent brackish marshes, river deltas, and tributary streams. All of these zones are part of the estuarine ecosystem and it is almost impossible to modify or rearrange one zone without modifying the others.

How do channels and the resulting spoil affect the estuarine ecosystem? Are these effects always bad or can they be good? Can a channel be modified to reduce or eliminate adverse effects? Can a channel be planned so that the environment is improved for fish and wildlife? Is there a right way and a wrong way to construct a channel and dispose of the spoil? The estuarine manager and conservationist deals with all these questions daily. Sometimes, answers are readily available. Too frequently, however, solutions are not apparent and a search of the literature confirms the inadequacy of our state of knowledge about channels and spoil in relation to the estuarine environment and the fish and wildlife resources harbored therein.

PURPOSE OF CHANNELS AND SPOIL

When we think of channels, most of us immediately think of navagation. When we think of spoiling, we envision a large hydraulic dredge discharging sediments on spoil mounds in a bay. Certainly when a channel is dredged, the resulting material must be disposed of in some manner.

Channels, however, are dug for many purposes other than navigation. Frequently, a channel (called a borrow pit) is created incidentally to obtain fill material to form new land in a bay or to raise the level of adjacent marshes. Channels also are dug to drain wetlands, accommodate pipelines, provide for waste disposal, transport water, create waterfront property, obtain minerals or buried shell, improve sport fishing, and for many other reasons. Regardless of why a channel is dug, however, two basic alterations to the estuarine environment are evident for all: (1) channels deepen a portion of the estuary and (2) spoil tends to reduce water depths (Kutkuhn, 1966). It is evident, therefore, that many of the problems and benefits associated with navigation channels apply equally to channels dug for other reasons.

METHODS OF CHANNEL CONSTRUCTION AND SPOIL DEPOSITION

The two basic methods of channel dredging are mechanical and hydraulic; modifications permit varying degrees of control over resulting spoil materials (Table 1).

Mechanical dredging by bucket dredge or dragline is used for construction and maintenance of small channels. Spoil can be relatively well controlled in a small area. This control is frequently desirable from a fish and wildlife standpoint, particularly when spoil is to be placed in shallow bays and brackish marshes instead of on adjacent uplands.

Hydraulic dredging is usually employed for construction of the larger channels, through deeper open-water areas, and for large maintenance operations. Spoil areas are necessarily large and proper control of spoil requires use of enclosed ponding areas. Ponding areas, however, usually are not practical in open, deeper water; thus, spoil is dispersed widely over the affected water bottoms.

As indicated in Table 1, the several methods of dredging that are available offer considerable latitude for disposition and control of resulting spoil.

PROBLEMS WITH CHANNELIZATION AND SPOIL DEPOSITION

The biological value of estuaries and their role in perpetuating fishery resources are well documented (Chapman, 1966; Clark, 1966; Diener, 1965; Gunter, 1967; McHugh, 1966, 1967; Skud and Wilson, 1960; Stroud, 1967, Sykes, 1965; and Sykes and Finucane, 1966). The literature dealing with the effects of channelization and spoil dumping in estuaries, though extensive, frequently lacks documentary evidence.

The influence and effect of channelization and spoil on the physical and chemical characteristics of an estuary can be measured precisely, but interpretation of the effects of the changes on the biota are extremely difficult. Few detailed studies have been undertaken to determine precisely how, when, where, and why the biological environment of an estuary is modified by physical and chemical change. Surprisingly, specific examples of direct loss of estuarine water areas and brackish marshes by deepening and filling, although not hard to obtain, have not been evaluated precisely. Probably the most disrupting and critical influence of channels and spoil in the estuarine environment is the direct physical loss of habitat. Measurement of habitat loss, therefore, gives some quantitative evidence of the rapid destruction of our estuaries.

TABLE 1—DREDGING EQUIPMENT AND SPOIL DEPOSITION

Dredging equipment and method	Principal use	Disposition of spoil	Spoil control	Comments
Mechanical dredge Bucket and dragline	Small channels	Place adjacent to channel	Small spoil area; minimum turbidity	Usually the preferred method; problem exists of blocking drainage and reducing water exchange or circulation
		or Place on barge	Remove from site	High cost usually prohibitive
Hydraulic dredge Hopper	Large channels	Remove from site to designated spoil area of preferably low-value habitat	Excellent at site; moderate at discharge point where turbidity is frequently high	Used where spoil area is not available near site or where adjacent spoil deposition would increase maintenance dredging
Pipe discharge	Large and medium size channels	Place in mounds adjacent to channel	Very poor unless spoil is retained by ring levee. Turbidity is high without ring levee and spoil area is large	Danger exists of segmenting bays and blocking drainage, tidal exchange, or circulation. Destruction of shallow bay and marshes by filling creates a major problem
Side broadcast discharge	Large channels	Scattered in layer over large area of bottom adjacent to channel	Depth of spoil on bottom can be controlled. Spoil area is large, turbidity is high, and silt is dispersed by currents	Can prevent bay segmentation but very large areas of water bottoms can be silted. Needs more study

Recently, gross measurements (U.S. Fish and Wildlife Service, 1967) reveal that dredging and filling have destroyed more than 200,000 acres of shallow bay nursery areas in Gulf and south Atlantic estuaries over the past 20 years. This figure does not include areas of coastal marsh which have been destroyed.

Schmidt (1966) reported that 45,000 acres of tidal marshes were destroyed between Maine and Delaware from 1954 to 1965. Spoil from dredging navigation channels and boat harbors accounted for 34 percent of this loss. Rounsefell (1964) reported that a single project in Louisiana, the Mississippi River-Gulf Outlet Channel, destroyed 23,606 acres of marsh and shallow-water nursery areas (17,058 acres by spoil deposition and 6,548 acres by deepening). Loss of habitat in the larger open bays and sounds near the Gulf of Mexico was not included in Rounsefell's figures. About 20 percent of the total surface area of Boca Ciega Bay, Florida, has been buried under waterfront lots (unpublished data, Bureau of Commerical Fisheries Biological Laboratory, St. Petersburg Beach, Florida) and in San Francisco Bay, 192,000 acres of formerly important estuarine habitat have been reduced to 37,000 acres, mostly by filling (Delisle, 1966).

On the basis of recent reports and maps (U.S. Army, Corps of Engineers, 1966a and 1966b), about 700 miles of Federal navigation channels in Texas have modified more than 13,000 acres of shallow bay estuarine nursery areas and destroyed almost 7,000 acres of marsh by deepening. Spoil from excavation of these channels destroyed an additional 23,000 acres of marsh and more than 55,000 acres of shallow bay areas (Table 2). The destruction of vital bay and marsh nursery areas in Texas from dredging of private channels for navigation and from other projects is not known, but must be great.

TABLE 2—ESTIMATED AREA OF ESTUARINE ZONE IN TEXAS DESTROYED OR SEVERELY DAMAGED BY EXCAVATION AND SPOIL FROM FEDERAL NAVIGATION CHANNELS

Type of habitat	Channel Length (Miles)	Channel Area (Acres)	Spoil Area (Acres)	Total Area (Acres)
Open bay waters	282	7,590	30,320	37,910
Bay shoreline zone	178	5,690	21,310	27,000
Tidal flats	36	920*	3,920	3,920
Marshes	193	6,980	23,000	29,980
TOTAL	689	20,260	78,550	98,810

*Not included in totals.

The Galveston Bay estuarine system is the largest and most important in Texas; it contains some 430,000 acres of surface water and brackish marsh. To date, about 67,000 acres of this valuable estuary have been physically destroyed, severely damaged and rearranged, or isolated. Channels and resulting spoil have accounted for 56 percent of this damage (U.S. Fish and Wildlife Service, in press).

Unfortunately, the examples of estuarine destruction which I have cited are being duplicated in most of the estuaries along the Gulf and south Atlantic coasts. Such losses of vital habitat are appalling, since it is nearly impossible to replace or restore these areas once they have been destroyed (Ford, 1960; Delisle, 1966). This problem was aptly summarized by Clark (1966) who stated, "This abundance of life [referring to the fishery resources of Atlantic coastal waters] is dependent upon the fertilizing effect of the coastal wetlands and protection they offer to many forms of life. The loss of any shallow coastal area will in some measure diminish life in the sea."

In addition to the direct physical loss of habitat, channelization and spoil deposition can modify the physical, chemical, and biological characteristics of the estuary in many other ways. The changes may be either beneficial or destructive, depending upon the particular estuary, the resources in question, or the point of view of the person reporting the change.

One of the first recorded complaints concerning canal dredging on the Gulf coast was recorded by Cary (1906). He reported that the many canals being dredged in the Louisiana coastal marshes were allowing large amounts of fresh water to enter the coastal bays during freshets, causing salinity reduction to levels dangerous for oysters. We seldom hear such complaints any longer. Instead, the waters in many areas are becoming too saline for oysters (McConnell, 1952a and 1952b; St. Amant, et al., 1956). The problems of increased salinity in Louisiana from channel construction were discussed by St. Amant, Friedrichs and Hadju (1958) as follows: "In recent times an increasing number of canals and deep water channels with their spoil levees have been cut across the marsh both laterally and vertically. This has resulted in changed direction of water flow, the damming of flow by levees, and has greatly increased the velocity of salt water flow into the marsh and fresh water flow through the marshes to the sea. The net result has been drastic increases in salinity in some areas and a rapid deterioration of productive marsh and bay conditions."

Numerous other examples of increased saltwater instrusion via deep channels have been studied or reported. Deep channels permit high-salinity waters from the sea to penetrate the upper reaches of an estuary and disperse throughout its area. Such a situation frequently develops in the Galveston estuary, Texas, during low river flow (Fig. 9).

One of the more striking examples of saltwater intrusion is that caused by the Mississipi River-Gulf Outlet Channel in Louisiana. This channel has helped high-salinity waters from the Gulf of Mexico to penetrate and disperse throughout thousands of acres of marsh and shallow bays and even has caused salinities in the 640-square mile Lake Pontchartrain to increase manyfold. The problem of saltwater intrusion via the Mississippi River-Gulf Outlet Channel was first predicted from a hydraulic model study (U.S. Fish and Wildlife Service, 1962; Tallant and Simmons, 1963), was discussed by Rounsefell (1964), and confirmed by subsequent field sampling

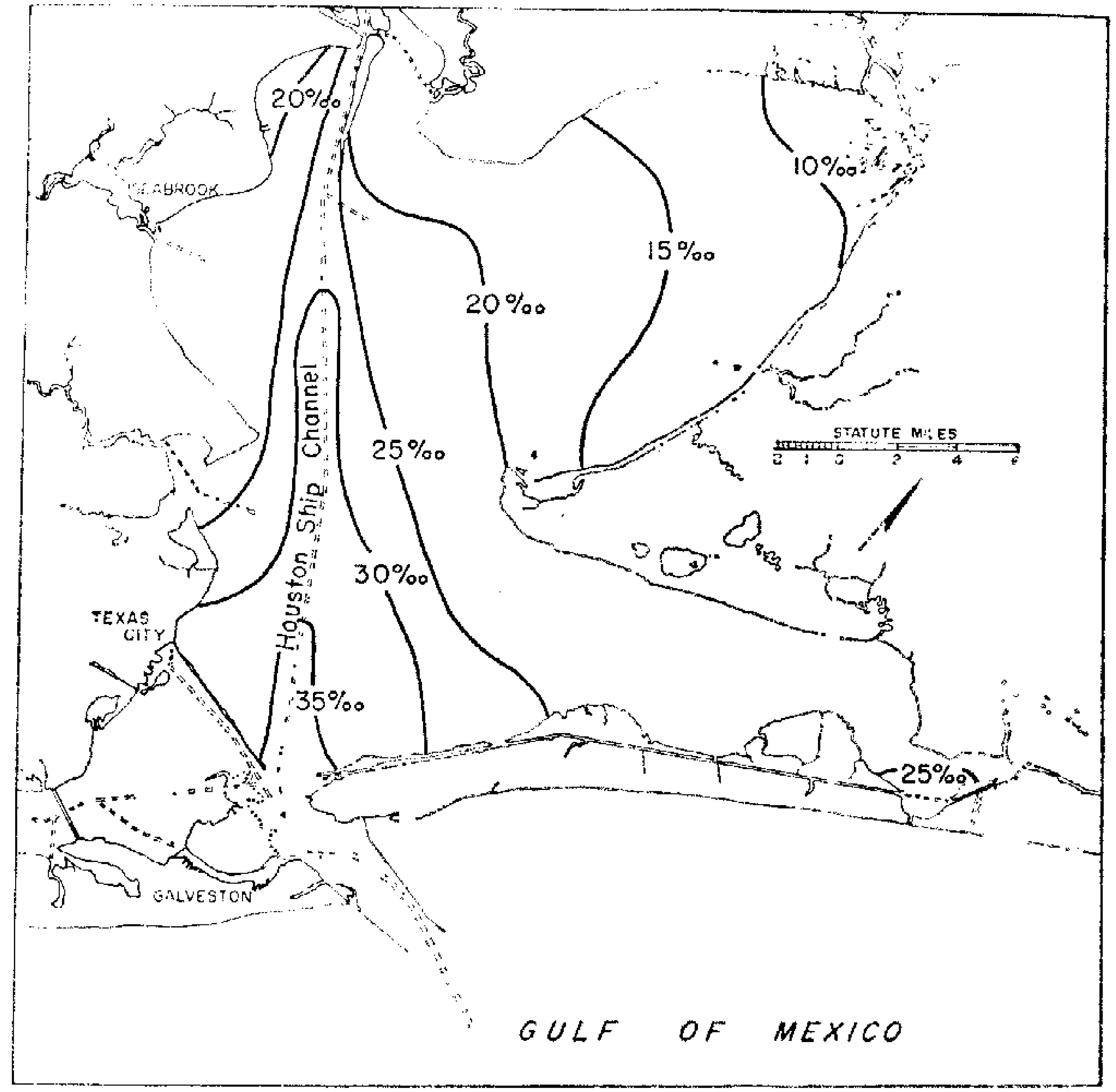

Figure 9—Salinity intrusion (at the bottom, in parts per thousand) into Galveston Bay, Texas, via the Houston Ship Channel in January 1963 during low river flow.

(Corps of Engineers and U.S. Fish and Wildlife Service, personal communication).

Considerable knowledge has been accumulated on salinity characteristics of estuaries and the factors that control them (U.S. Army, Corps of Engineers, 1965). It is now possible to predict changes in major features in the salinity regime of certain types of estuaries that would accompany channel construction or channel modification (French, 1960; Ippen and Harleman, 1961; Sakou, 1963; Simmons and Lindner, 1965). Unfortunately, conservationists are not as yet using this knowledge to best advantage.

The modification by channels of tidal exchange between an estuary and the sea can have far greater consequences than merely encouraging or reducing salt-water instrusion. Tidal currents, assisted by wind, furnish the energy for horizontal translation and mixing throughout an estuary. Increased tidal velocity tends to convert a stratified estuary to vertical homogeneity (Pritchard, 1955). Problems of excessive algal blooms in Great South Bay and Moriches Bay, New York, which seriously reduced oyster producing capacity, were studied by Ryther (1954) and Ryther et al. (1958). Considerable improvement resulted when Moriches inlet was reopened to restore effective exchange with the sea. Odum and Wilson (1962) noted the possibility that bays with little flushing may develop higher productivity and more effective regeneration of nutrients. Perhaps this is one of the reasons why Gulf estuaries in which the tides are small are so productive.

Segmentation of bays by channels and spoil banks can also cause serious derangements. Large areas of shallow water and brackish marsh frequently are isolated to be as effectively lost for nursery areas as if they were physically destroyed. Kutkuhn (1966) noted that deposition of spoil from channel dredging may subdivide a bay in such a way that subsequent changes will render the segmented portions shallower and less useful as nursery areas. Shoaling has become so serious in Lake Grand Ecaille and Bay Long, Louisiana, because of severe silting caused by bay segmentation, that boats can no longer operate out of marked channels (Waldo, 1958).

Problems arising from increased turbidity and sedimentation differ among estuaries. Obvious damage from high turbidity may occur in one estuary but not even be noticed in another. It is necessary, therefore, to characterize an estuary before describing the effects of turbidity and sedimentation. Most Gulf and south Atlantic estuaries can be placed in two broad categories, each of which is affected differently by increases in turbidity and sedimentation. These categories may be described as follows:

1. Receives considerable tributary fresh water containing large amounts of sediment. Waters, therefore, are relatively turbid naturally and a well-defined salinity gradient (from nearly fresh water to sea water) is usually present. Beds of submerged aquatic vegetation are scarce, if present at all, but emergent vegetation forms large areas of bordering brackish marsh. This type of estuary, which is very productive, is almost continuous from Galveston Bay, Texas, to Mobile Bay, Alabama.
2. Salinities are relatively high and waters comparatively clear. Tributary discharge and accompanying sediment loads are small in relation to size of the estuarine basin. Very little bordering marsh is evident, but extensive beds of submerged aquatic vegetation are present.

In the naturally turbid estuary, increases in turbidity, which frequently are temporary and local, are difficult to detect and often are not noticed. Once silt is put into suspension by dredging it behaves as if natural suspending agencies (wind, waves, flooding, tide) put it there (Mackin, 1961). Because the heavier material put into suspension settles quickly, turbidities a short distance from the spoil site rarely exceed natural levels caused by wind (Cronin, 1967). Mackin (1961) reported that turbidities 300 feet from the discharge pipe of a hydraulic dredge did not exceed those observed on occasion under natural conditions in a naturally turbid Louisiana Bay. He also stated that the amount of fines (silt and clays) drifting away from the spoil site did not exceed 1 percent of the total materials removed. With increasing distance from the spoil area dilution was very effective in reducing turbidity.

The problems of increased turbidity in the clear-water estuaries that have large beds of submerged aquatic vegetation, however, are entirely different. Even temporary increases in turbidity can cause serious damage. Turbidity obviously interferes with light transmission and photosynthesis and usually increases oxygen demand (Odum and Wilson, 1962). The reduced penetration of sunlight will cause beds of submerged aquatic vegetation to die and prevent them from becoming reestablished. Periods of high turbidity are frequently prolonged because wave action erodes spoil banks and resuspends fine sediments which have settled on nearby bottoms. Even after spoil areas have stabilized, periodic maintenance dredging can perpetuate the problem indefinitely.

The rearrangement of bottom sediments by siltation can also have a disturbing influence on an estuary. The heavier particles put into suspension by a hydraulic dredge settle out within a short distance but the remaining fine material can be carried considerable distances and "coat" a large area of bottom—even form a "false" bottom that will not support benthic animals (Hollis et al., 1964). Usually, however, fine materials become part of the total sediment structure of an estuary to be continually rearranged, shifted, and transported seaward by waves and currents. In a shallow Louisiana bay, Mackin (1961) reported that silt was carried and deposited as far as 1,300 feet from a working dredge. Wilson (1950) reported that silt extended about 300 yards from a hydraulic shell dredge working in a Texas bay. Hellier and Kornicker (1962) discovered that sediments discharged from a hydraulic dredge during construction of the Gulf Intracoastal Waterway were carried at least one-half mile where they were deposited to a depth of 22 centimeters in 1 week and 33 centimeters within 18 months.

Much of the information presently available to the biologist concerning channelization and spoil was obtained from study of the effect of increased turbidity and silting on oysters and from attempts to prove that the oyster is a hearty creature capable of surviving extreme abuse. Almost ignored in these studies was the direct physical destruction of shallow bays by deepening and filling. What good results from proof that a temporary increase in turbidity did not harm an oyster when the spoil deposit which promoted the turbidity destroyed hundreds of acres of bay or marsh? It is about time things were put in their proper perspective.

BENEFITS FROM CHANNELIZATION AND SPOIL

Channel construction in a shallow bay or brackish marsh frequently can benefit the fishery resources even though some habitat may be destroyed by spoil. Channels can and do connect isolated waters and marsh areas with the estuary proper to enlarge the estuarine nursery area. Channels have opened up considerable nursery areas in Louisiana and Texas. Much of the coastal marsh between Sabine Lake and Galveston Bay, Texas, was formerly isolated and not available to estuarine animals. Dredging of the Gulf Intracoastal Waterway across 40 miles of this marsh opened thousands of acres of nursery area to estuarine shrimp, crabs, and fish. Unfortunately, some of this marsh since has been reisolated to prevent salt-water intrusion into nearby rice-growing areas.

Because many estuarine areas are partially isolated or far removed from a source of saltwater, they have extremely low salinities and provide nursery habitat for very few species. The penetration of these areas by channels frequently is accompanied by increases in salinity that permit more species to be accommodated. The danger exists, however, that salinity will be increased so much as to alter the habitat adversely, particularly the vegetation. Improvement of habitat conditions by saltwater intrusion to a specific area often is accompanied by habitat deterioration elsewhere from excessively high salinity.

Severe winter storms locally called "northers," have caused massive fish kills in the shallow Texas bays (Gunter, 1941; Gunter and Hildebrand, 1951). The deeper waters in channels do not chill as fast as shallow bay waters and thus provide fish with a route of escape or refuge. The 30-foot-deep Offatts Bayou in Galveston Bay is noted for its excellent sport fishing during and following winter storms.

The Gulf Intracoastal Waterway through the Laguna Madre of Texas now provides an avenue of escape for fish from both cold and the excessive hypersaline conditions that develop in summer from high evaporation (Simmons, 1957). The Gulf Intracoastal Waterway has also improved water circulation in the Laguna Madre and thus has lessened excessive hypersalinity (Breuer, 1962). Salinity greater than 100 parts per thousand was reported by Collier and Hedgpeth (1950) before construction of the Gulf Intracoastal Waterway, but since has not exceeded 80 parts per thousand (Simmons, 1957; Breuer, 1962).

Another benefit attributed to channel construction is the release of nutrients bound in the bottom sediments (Gunter, 1967). Although Gunter (1957) recognized that the deleterious effects from spoil are real, but localized, he hypothesized that the release of nutrients may more than offset the damage done.

PLANNING FOR CHANNELS AND SPOIL DEPOSITION

The Bureau of Commercial Fisheries in cooperation with the Bureau of Sport Fisheries and Wildlife and State conservation agencies reviews the plans for all channel construction in the nation's estuaries. When it is evident that channel construction and spoil deposition or both will have deleterious effects on fish and wildlife resources or the estuarine environment, a report is prepared and submitted to the Corps of Engineers. Each report contains an appraisal of the problems the project would generate and specifically

states how and to what extent fish and wildlife resources would be adversely affected. The report concludes with specific recommendations for modifying project plans to reduce or eliminate anticipated project damage. Occasionally, it is possible to include recommendations to improve fish and wildlife habitat.

The reports for Federal navigation channels are directed to, and coordinated with, the District Engineer responsible for a particular project. For private projects requiring a Federal permit for construction in navigable waters, the Corps of Engineers forwards the recommendations of the Fish and Wildlife Service to the applicant. If the applicant agrees to the recommendations, he modifies his proposed plan, resubmits his application to the Corps of Engineers, and is then issued a permit. Frequently it is necessary for the applicant and the Fish and Wildlife Service to discuss the recommended modifications and agree to a compromise. If a compromise cannot be reached or if the applicant refuses to consider the recommendations, the decision to issue the permit rests solely with the Corps of Engineers.

In the review of plans for channel construction and spoil deposition, several factors must be considered and questions asked. Is the channel alignment satisfactory or should it be moved? Will saltwater intrusion be a problem? Will excessive drainage result? Will turbidity increase enough to be damaging? How much high-value habitat will be destroyed? Is there a better way to handle the spoil? Will oyster reefs be damaged? How many waterways will be blocked and how much habitat isolated? Will segmentation of a bay be a problem? Will nearby isolated habitat be connected to the estuary? Will water circulation or tidal exchange be modified adversely? Will natural waterways and tributaries be destroyed or usurped? These are but some of the questions that must be asked when appraising each proposal for channel construction and deposition of spoil in the estuaries and marshes. Finding answers to such questions or solutions to the problems they pose can be extremely difficult; a simple solution usually is not available.

On the basis of review of hundreds of channel projects, however, we have developed general guidelines and criteria to assist us to formulate recommendations for project modification to serve the fish and wildlife resources. These guidelines and criteria are not intended to be all inclusive, nor are they minimum or maximum standards that must be adhered to absolutely. Furthermore, they best can be applied by the trained biologist who is familiar with the area in question.

1. Channels should not cross nor should spoil be placed on high-value habitat. High-value habitat in most estuaries includes, but is not limited to, brackish marshes, vegetated shoreline zones, beds of submerged aquatic vegetation, protected shallow waters near shore, oyster reefs, and small meandering tributaries (bayous) in the tidal zone.
2. To provide for maximum water exchange and circulation, spoil should be placed in mounds at least 1,000 feet apart on alternating sides of a channel.

3. Spoil should not be placed in the water closer than 500 feet from the shoreline of shallow, protected bays.
4. Natural drainage channels and waterways should not be blocked by spoil. Isolation of an area is far more damaging than changes in the environment which may result from salt-water intrusion.
5. The integrity of natural waterways should be maintained. This principle is especially applicable to dead-end access channels and pipeline canals.
6. Spoil should be placed on uplands (above mean high tide) where possible; otherwise it should be confined by ring levees, if necessary, to as small an area as practical.
7. Spoil deposition sites should be retained for future maintenance spoil.
8. Where possible, isolated waters and marshes should be connected to the estuary to enlarge the area of nursery habitat.

HABITAT REHABILITATION

Every opportunity should be taken to study and develop methods for rehabilitating estuarine areas which have been severely damaged or destroyed. The indiscriminate dumping of millions of cubic yards of spoil from channel excavation has destroyed submerged aquatic vegetation, marshes, and shallow bays. The shorelines of spoil "islands" usually are unstable and devoid of emergent plants. Shallow flats created by spoil deposition seldom develop a vegetative cover. If beds of submerged aquatic plants can be reestablished or if emergent vegetation can be made to grow along the hundreds of miles of barren shoreline, surely the productiveness of our estuaries will remain high or be improved.

To accomplish this rehabilitation, however, we must learn how to control excessive turbidity and to stabilize shorelines. We must learn how to reestablish submergent vegetation economically and how best to vegetate barren shorelines. Perhaps the method of spoil disposal can be controlled to facilitate the growth of vegetation.

The entire field of habitat rehabilitation promises to yield great rewards but unfortunately has been sadly neglected. We know that thousands of acres of estuarine habitat have been damaged and destroyed and that the future promises an increase of this problem. It is time now to stop, and if possible, to reverse this destructive trend. Habitat rehabilitation certainly is one way to accomplish this goal.

LITERATURE CITED

Breuer, Joseph P. 1962. An ecological survey of the lower Laguna Madre of Texas, 1953-1959. Univ. of Tex., Publ. Inst. Mar. Sci., 8: 153-183.

Cary, L. R. 1906. The conditions for oyster culture in the waters of the Parishes of Vermilion and Iberia, Louisiana. Gulf Biological Sta. Bull. 4: 6-27.

Chapman, Charles R. 1966. The Texas Basins Project. Amer. Fish. Soc., Sp. Publ. No. 3: 83-92.

Clark, John. 1966. Why saltwater fishes need the shallow coastal estuaries. Proc. of the Symp. on Estuarine Ecology of Coastal Waters of North Carolina; Univ. N. C. Water Resour. Inst.: 25-34.

Collier, Albert, and Joel W. Hedgpeth. 1950. An introduction to the hydrography of the tidal waters of Texas. Univ. Tex., Publ. Inst. Mar. Sci., 1(2): 125-194.

Cronin, L. Eugene. 1967. The role of man in estuarine processes. In "Estuaries;" A.A.A.S. Publ. No. 83: 667-689.

Delisle, Glenn. 1966. Preliminary Fish and Wildlife plan for San Francisco Bay-estuary. Calif. Dept. of Fish and Game background report for the San Francisco Bay Conservation and Development Commission. 118 p.

Diener, Richard A. 1965. Texas estuaries and water development projects. Proc. Ninth Ann. Waters for Texas Conference, Nov. 23-24, 1964: 25-31.

Ford, T. B. 1960. Report of the River Basins Studies Section, Fish and Game Division. Eighth Biennial Rept., La. Wildl. and Fish. Comm., 1958-1959; 39-42.

French, John L. 1960. Tidal flow in entrances. U.S. Army, Corps of Engineers Committee on Tidal Hydraulics Tech. Bull. No. 3: 49 p.

Gunter, Gordon. 1941. Death of fishes due to cold on the Texas coast. Ecology, 22(3): 203-208.

———— 1957. How does siltation affect fish production? Natl. Fisherman, 38(3): 18-19.

Gunter, Gordon. 1967. Some relationships of estuaries to the fisheries of the Gulf of Mexico. In "Estuaries;" A.A.A.S. Publ. No. 83: 621-638.

————, and H. H. Hildebrand 1951. Destruction of fishes and other organisms on the south Texas coast by cold wave of January 28-February 3, 1951. Ecology, 32(4): 731-736.

Hellier, T. R., and L. S. Kornicker. 1962. Sedimentation from a hydraulic dredge in a bay. Univ. Tex., Publ. Inst. Mar. Sci, 8: 212-215

Hollis, E. H., J. G. Boone, C. R. DeRose, and G. J. Murphy. 1964. A literature review of the effects of turbidity and siltation on aquatic life. Staff report, Dept. of Chesapeake Bay Affairs, Annapolis, Md., Mimeo, 26 p.

Ippen, Arthur T., and Donald F. Harleman. 1961. One-dimensional analysis of salinity intrusion in estuaries. U.S. Army, Corps of Engineers Committee on Tidal Hydraulics Tech. Bull. No. 5: 52 p.

Kutkuhn, Joseph H. 1966. The role of estuaries in the development and perpetuation of commercial shrimp resources. Amer. Fish. Soc., Sp. Publ. No. 3: 16-36.

Mackin, J. G. 1961. Canal dredging and silting in Louisiana bays. Univ. Tex., Publ. Inst. Mar. Sci., 7: 262-314.

McConnell, J. N. 1952a. Louisiana oyster future. Louisiana Conservationist, Jan. 1952, 4(5): 5-9.

———— 1952b. Report of Division of Oysters and Water Bottoms. Fourth Biennial Rept. Dept. of Wildl. and Fish., State of La. for 1950-1951: 141-160.

McHugh, J. L. 1966. Management of estuarine fisheries. Amer. Fish. Soc., Sp. Publ. No. 3: 133-154.

———— 1967. Estuarine nekton. In "Estuaries;" A.A.A.S. Publ. No. 83; 581-620.

Odum, H. T., and R. F. Wilson. 1962. Further studies on reaeration and metabolism of Texas bays. Univ. Tex., Publ. Inst. Mar. Sci., 8: 23-55

Pritchard, D. W. 1955. Estuarine circulation patterns. Proc. Am. Soc. Civil Engrs., 81: 1-11.

Rounsefell, George. A. 1964. Preconstruction study of the fisheries of the estuarine areas traversed by the Mississippi River-Gulf Outlet project. U.S. Fish and Wildl. Serv., Fish. Bull., 63(2): 373-393.

Ryther, J. H. 1954. The ecology of phytoplankton blooms in Moriches Bay and Great South Bay, Long Island, New York. Biol. Bull. 106, 198-209.

————, R. F. Vaccaro, E. M. Hulburt, C. S. Yentsch, and R. R. L. Guillard 1958. Report on a survey of the chemistry, biology, and hydrography of Great South Bay and Moriches Bay conducted during June and September 1958, for the townships of Islip and Brookhaven, Long Island, New York. Woods Hole Oceanogr. Inst. Ref. 58-57.

Sakou, Toshitsugo. 1963. The salinity regime and exchange characteristics of a shallow coastal bay system. Tex. A&M Univ., Dept. Oceanogr. and Meteor. Tech. Report 63-21T.

Schmidt, Ralph A. 1966. Needed—a coastwise comprehensive program for development of estuaries. Amer. Fish. Soc., Sp. Publ. No. 3: 102-109.

Simmons, Ernest G. 1957. An ecological survey of the Laguna Madre, Texas. Univ. Tex. Publ. Inst. Mar. Sci., 4(2): 156-200.

Simmons, H. B., and C. P. Lindner. 1965. Hydraulic model studies of tidal waterway problems. In "Evaluation of present state of knowledge of factors affecting tidal hydraulics and related phenomena." U.S. Army, Corps of Engineers Committee on Tidal Hydraulics Report No. 3: Chapt. IX; 21 p.

Skud, Bernard E., and W. B. Wilson 1960. Role of estuarine waters in Gulf fisheries. Trans. 25th N.A. Wildlife. Conf.: 320-326.

St. Amant, Lyle S., E. J. Fairchild, A. V. Friedrichs, and B. E. Strawbridge. 1956. Report of Biological Section; Oysters, Water Bottoms, and Seafood Division. Sixth Biennial Rept., La. Wildl. and Seafood Comm., 1954-1955: 143-160.

————, A. V. Friedrichs, and Emory Hadju. 1958. Report of the Biological Section; Oysters, Water Bottoms, and Seafood Division. Seventh Biennial Rept., La. Wildl. and Fish. Comm., 1956-1957: 71-92.

Stroud, R. H. 1967. Fisheries vs. shell dredging. Sport Fish. Inst. Bull No. 184: 5-7.

Sykes, James E. 1965. Multiple utilization of Gulf coast estuaries. Proc. 17th Ann. Conf. S.E. Assn. Game and Fish. Comm.: 323-326

————, and John H. Finucane 1966. Occurrence in Tampa Bay, Florida, of immature species dominant in Gulf of Mexico commercial fisheries. U.S. Fish and Wildl. Serv., Fish. Bull., 65(2): 369-379.

Tallant, I. C., and H. B. Simmons. 1963. Effect in Lake Pontchartrain, Louisiana, of hurricane surge control structures and Mississippi River-Gulf Outlet Channel; hydraulic model investigation. U.S. Army, Corps of Engineers, Waterways Exp. Sta. Tech. Rept. 2-636.

U.S. Army, Corps of Engineers. 1965. Bibliography on tidal hydraulics. Committee on Tidal Hydraulics Rept. No. 2, Suppl. No. 4: 218 p.

———— 1966a. Maps of the Gulf Intracoastal Waterway, Texas; Sabine River to the Rio Grande and connecting waterways. Dept. of the Army, Galveston District, Corps of Engineers, Galveston, Tex., 59 p.

U.S. Army, Corps of Engineers. 1966b. Project maps, Galveston District. U.S. Army, Galveston District, Corps of Engineers, Galveston, Texas.

U.S. Fish and Wildlife Service 1962. A detailed report on hurricane study area No. 1; Lake Pontchartrain and vicinity, Louisiana. Bur. Sport. Fish. and Wildl., Region 4, Atlanta, Ga., Processed, 32 p.

———— 1967. Hearings on estuarine areas, House Merchant Marine and Fisheries subcommittee on fisheries and wildlife conservation, March 6, 8, 9, 1967. The Conservation Foundation Letter, May 22, 1967: 8.

———— (In press) Biological Laboratory, Galveston, Texas, Fishery research for the year ending June 30, 1967. U.S. Fish and Wildl. Serv., Circular.

Waldo, E. 1958. Report of the Biological Section; Oysters, Water Bottoms, and Seafood Division. Seventh Biennial Rept., La. Wildl. and Fish. Comm., 1956-1957: 93-95.

Wilson, W. B. 1950. The effects of dredging on oysters in Copano Bay, Texas. Annual Rept. of the Mar. Lab. of the Tex. Game, Fish, and Oyster Comm., 1948-1949: 1-50.